



Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

Titanium mesh cranioplasty in pediatric patients after decompressive craniectomy: Appropriate timing for pre-schoolers and early school age children

Han-song Sheng^{a,1}, Fang Shen^{b,1}, Nu Zhang^a, Fen-chun Lin^a, Dan-dong Li^a, Ming Cai^a, Guo-qiang Jiang^b, Jian Lin^{a,*}

^a Department of Neurosurgery, Second Affiliated Hospital of Wenzhou Medical University, Wenzhou, China

^b Department of Orthopaedic Surgery's Spine Division, The Affiliated Hospital of Medical School of Ningbo University, Ningbo, 315020, Zhejiang, China

ARTICLE INFO

Article history:

Paper received 11 December 2018

Accepted 16 April 2019

Available online 20 April 2019

Keywords:

Cranioplasty
Decompressive craniectomy
Pediatric
Titanium mesh
Pre-schooler

ABSTRACT

Purpose: There is little knowledge on the growth of cranial defects, appropriate timing and outcomes of application of titanium mesh for cranioplasty in the pediatric population, especially pre-school age (2–5 years old) and school age (6–12 years old) children. We hypothesised that cranioplasty for pre-schoolers could be delayed to school age due to the expected cranium growth, whereas, for the school age group, it is better to perform routine cranioplasty (3–6 months) to protect the brain and therefore ensure their timely return to school life.

Materials and methods: A retrospective review of pediatric patients (2–12 years old) who underwent titanium mesh cranioplasty for cranial defects from 2006 to 2012 was performed. Patient demographic data, radiological data, and clinical information were collected. Specifically, cranial defect sizes were evaluated by three-dimensional (3D) reconstruction of computed tomography data after craniectomy, before cranioplasty and 2-years after cranioplasty. Patients were routinely followed up at an outpatient clinic for complications and school attendance.

Results: A total of 18 titanium mesh cranioplasties were performed in 18 patients. The average interval between craniectomy and cranioplasty was 3 years for pre-schoolers and 4 months for the school age group. Patients in the pre-schooler group showed significant enlargements in cranial defects during the interval as compared with the school age group (26% vs. 4%, $P < 0.05$). There were no surgery-related complications except in one patient, who had titanium mesh exposure 11 months later. Two years after cranioplasty, there was no significant difference in mild cranial defect enlargements between the two groups (11% vs. 6%, $P > 0.05$). Patients were followed for an average of 5 (range, 2–8) years. All patients had satisfactory recovery of cranial contour, sufficient protection of the brain and active participation in school study. All patients had satisfactory recovery of cranial contour, sufficient protection of the brain and active participation in school.

Conclusion: Timing of titanium mesh cranioplasty after decompressive craniectomy based on their age is a workable solution for school-age pediatric patients. The enlargement of cranium defects in pre-schoolers supports a delayed repair until school age. The long-term outcomes for these patients with titanium mesh cranioplasty are favourable.

© 2019 European Association for Cranio-Maxillo-Facial Surgery. Published by Elsevier Ltd. All rights reserved.

* Corresponding author. Department of Neurosurgery, Second Affiliated Hospital of Wenzhou Medical University, 109 Xueyuan Western Road, Wenzhou, Zhejiang, 325027, China.

E-mail addresses: shs951052@163.com (H.-s. Sheng), fshen@aliyun.com (F. Shen), wzneurosurgery@outlook.com (N. Zhang), 147387544@qq.com (F.-c. Lin), lidanong2006@163.com (D.-d. Li), c.mtracy@163.com (M. Cai), 13605740504@163.com (G.-q. Jiang), linjian74@yeah.net (J. Lin).

¹ Han-song Sheng and Fang Shen contribute equally to this work.

1. Introduction

Brain trauma and subsequent decompressive craniectomy (DC) is the leading cause of cranial defects in children in developing countries such as China (Xuequn et al., 2011; Jiang, 2013; Chong et al., 2017). As children survive and recover from the trauma, a

subsequent cranioplasty is indicated not only to protect vital neural structures, but also to offer restoration of the cranial contour for cosmetic reasons (Narayan and Persing, 2002). Moreover, as pediatric patients return to normal social lives, most of them will go to school, and cranioplasty has been proposed to produce further benefit by improving neurological function by maintaining normal circulation of cerebrospinal fluid and cerebral blood flow (Halani et al., 2017), and thus potentially returning to normal school attendance for children.

While autologous bone is always the best choice whenever possible, it may lack practicability due to availability and bone flap resorption, especially in the pediatric population (Shah et al., 2014; Fu et al., 2016). Other substitutes have been used in the history of neurosurgery. Commonly used artificial materials include polymethylmethacrylate (PMMA), hydroxyapatite, titanium meshes and polyetheretherketone (PEEK) (Piitulainen et al., 2015; Plum and Tatum, 2015). As far as China is concerned, titanium meshes have been the most popular graft of choice in the past few decades because of their advantages; in particular, custom-made titanium meshes based on preoperative computed tomography (CT) have been shown to deliver good skull-shape symmetry and brain protection (Mukherjee et al., 2014; Williams et al., 2015; Ma et al., 2018).

Although still in dispute, cranioplasty 3–6 months after injury has been proposed to produce some neurological benefits in adult patients, such as preventing motor trephine syndrome (MTS) (Jeyaraj, 2015). However, there is a paucity of data available regarding timing of cranioplasty in the pediatric population, who are undergoing active neurological development. Previous literature has focused on the timing of cranioplasty with autologous bone grafts, with a main emphasis on its relationship with bone resorption (Piedra et al., 2012; Rocque et al., 2013; Waqas et al., 2017). However, little knowledge is available on timing of titanium mesh in children with the major concern over their growing skulls. Here, we hypothesised postponing cranioplasty with titanium mesh for pre-schoolers until they reach school age because of the potential growth of the cranium during this active growth period. On the other hand, for school-age children, cranioplasty was performed with routine timing of 3–6 months. We present data on the changes in cranial defect sizes through craniectomy, cranioplasty and 2 years after operation, and early and late complications following titanium mesh cranioplasty in both patient groups.

2. Materials and methods

In this retrospective single-center case series study, operation records in an electronic health record database were used to identify all patients who underwent titanium mesh cranioplasty using a custom-made implant at our hospital, a tertiary academic pediatric medical center, between 2006 and 2012. Data such as patient demographics, age at craniectomy and cranioplasty, size and location of the defect, quality of the covering scalp, preoperative conditions, and perioperative complications were collected. CT imaging was routinely performed for evaluation of the defect and cranium growth, manufacture of customized three-dimensional (3D) titanium mesh and measuring cranial contour after cranioplasty. Specifically, the measurement of cranial defect sizes was achieved by using CTSim software. The DICOM file obtained from CT was imported into CTSim and the defect cranium was reconstruct based on the contour of the contralateral healthy side. An Institutional Review Board approval was obtained for performing this study in accordance with the Declaration of Helsinki. Informed consent was obtained from patients' parents regarding publication

of the relevant data. Statistical data were analysed using the SPSS 22.0 software package (SPSS Inc., Chicago, IL, USA). Continuous variables were presented as mean \pm standard deviation (SD). Data comparisons between groups were carried out with the Mann–Whitney *U* test. A *P* value < 0.05 was considered statistically significant.

3. Results

3.1. Clinical data

Over the study period, a total of 18 titanium mesh cranioplasties were performed on 18 patients, 9 pre-schoolers and 9 school-age patients (Tables 1 and 2). The most common causes for prior brain trauma were motor vehicle accidents and falls. All patients had prior cranial surgeries with decompressive craniectomy, which resulted in skull defects of varied location and size (17–120 cm²). There was no significant difference in defect sizes between the two groups after initial craniectomy (70 cm² vs. 74 cm², *P* > 0.05). Overlying scalp conditions were routinely evaluated before secondary cranioplasty; there was no sign of atrophy, and no tissue expansion was needed in our series. The average interval between the cranial defect and reconstruction for the pre-schooler group was 3 years (range 1–4 years) and for the school age group was 4 months (range 3–6 months). However, the enlargements in cranial defect sizes in pre-schooler patients during the waiting period (26%, range 13–41%) were significantly larger than that of the school-age group (4%, range 3–5%) (*P* < 0.05).

3.2. Surgical techniques

Standard peri-operative antibiotic prophylaxis was given, and surgery was performed under general anaesthesia. The incision was made on the prior scars and the use of cautery was minimised during soft tissue dissection along the incision. As a general principle, dural repair and enlargement were performed at the initial DP, with either patients' own fascia when possible or artificial dura mater, to reduce adhesions between the cortex/dura and the overlying temporalis muscle/galea at the subsequent cranioplasty. Subperiosteal dissection was performed to maintain the maximum thickness of the scalp. All titanium meshes were custom-made (modelled on preoperative CT imaging of the cranium). Therefore, the titanium mesh fit the contour of the defect area and was secured by titanium screws. Skin incisions were closed with galeal sutures followed by resorbable sutures. Drainages were placed and removed the second day after operation. The average blood loss was about 200 mL and no blood transfusion was required.

3.3. Clinical outcomes

No patient required a postoperative ICU stay and the average hospital stay was 7 (range, 3–10) days for pre-schooler group and 8 (range, 5–10) days for school age group. All patients had good healing of the scalp incision after cranioplasty and no patient had perioperative complication within 30 days. However, one patient in the school-age group had titanium mesh exposure 11 months later. The initial treatment was local debridement and antibiotics, but finally the implant was removed and bone debris was found just beneath the skin defects during surgeries. A second cranioplasty with customized 3D titanium mesh was performed 1 year after implant removal and the patient had no further problems at later follow-up. Two years after cranioplasty, there was no significant difference in terms of the mild enlargements of cranial defect sizes

Table 1
Patient demographics and characteristics related to titanium mesh cranioplasty in Pre-schoolers (2–5 years old).

No.	Gender	Age ^a at injury	Age ^a at CP	Interval ^a	Cause	Site	Defect size (cm ²)			Increased (%)			Inpatient stay ^b	Complication	Follow-up ^a
							After DC	Before CP	2-year post-CP	Before CP vs. After DC	2-year post-CP vs. Before CP	2-year post-CP vs. After DC			
1	F	2	6	4	Fall	Left frontal	43	49	54	14	10	24	5	no	6
2	M	3	6	3	Fall	Left frontal	42	55	60	31	12	43	9	no	5
3	M	3	6	3	Fall	Left temporal	47	60	64	28	8	35	3	no	6
4	F	3	6	3	Fall	Right frontal	120	142	150	18	7	25	4	no	7
5	M	2	6	4	MVA	temporal parietal occipital	80	109	118	36	11	48	10	no	4
6	M	4	6	2	MVA	Right temporal parietal	64	89	98	39	14	53	5	no	8
7	M	3	6	3	MVA	Left temporal occipital	86	97	108	13	12	25	4	no	5
8	M	5	6	1	Fall	Left frontal temporal	100	116	120	16	4	20	10	no	4
9	M	3	6	3	MVA	temporal parietal occipital I Right frontal parietal	51	72	81	41	18	59	10	no	6
Mean				3			70	88	97	26	11	37	7		6
SD				0.9			26.2	30.0	30.1	10.6	3.8	13.5	2.8		1.2

F = Female; M = Male; CP = cranioplasty; MVA = Motor Vehicle Accident; DC = decompressive craniectomy.

^a Years.

^b Days.

Table 2
Patient demographics and characteristics related to titanium mesh cranioplasty in school age children (6–12 years old).

No.	Gender	Age ^a at CP	Interval ^b	Cause	Site	Defect size (cm ²)		Increased (%)		2-year post-CP vs. Before CP	2-year post-CP vs. After DC	2-year post-CP vs. After DC	Inpatient stay ^c	Complication	Follow-up ^d
						After DC	Before CP	Before CP	After DC						
1	M	6	3	Fall	Right parietal occipital	17	18	4	8	12	6	6	no	6	
2	F	8	5	MVA	Left frontal temporal	80	83	4	8	11	9	9	no	5	
3	M	8	6	Fall	Right frontal temporal parietal	90	93	3	3	7	5	5	no	4	
4	F	10	3	MVA	Left temporal parietal	48	50	4	8	13	8	8	no	3	
5	F	13	3	Blunt Hit	Left temporal parietal	80	83	4	4	8	10	10	no	5	
6	M	10	4	Fall	Left temporal parietal	56	59	5	9	14	9	9	no	4	
7	F	12	5	Fall	Left frontal temporal parietal occipital I	120	123	3	4	7	9	9	mesh exposure	5	
8	M	12	3	Fall	Right frontal temporal	90	93	3	4	8	6	6	no	4	
9	F	11	4	Fall	Right temporal	81	84	4	5	9	8	8	no	2	
		8	4			74	76	4	6	10	8	8		4	
Mean		2.3	1.1			29.6	30.2	0.8	2.2	2.8	1.7	1.7		1.2	
SD															

F = Female; M = Male; CP = cranioplasty; MVA = Motor Vehicle Accident; DC = decompressive craniectomy.

^a Years.

^b Months.

^c Days.

between the two groups during the 2-year period (11% vs. 6%, $P > 0.05$). All patients were followed up for an average of 5 years (range 2–8 years), and all cranioplasties were firm despite these slight enlargements, with satisfactory cosmetic outcomes (symmetrical cranial contours) achieved in all patients. All patients were admitted to the local primary school without major performance problems when consulted at outpatient follow-ups.

3.4. Illustrative case 1

Case 1 was a 6-year-old boy who had a cranial defect and was admitted for titanium mesh cranioplasty. On review of his medical history, he received a left temporal parietal DC because of traumatic brain injury 3 years ago. During the initial emergence decompression procedure, a left temporal parietal bone flap, measuring 47 cm² on CT (Fig. 1A–C), was removed for a left subdural haemorrhage, and a right bone flap was returned after evacuation of an epidural haemorrhage. In order to reduce adhesions between the cortex/dura and the overlying temporalis muscle/galea, artificial dura mater was used for dural repair and enlargement. 3D CT reconstruction of the cranium for titanium mesh modelling before cranioplasty revealed enlargement of the defect to 60 cm² (28% increase) and partial regrowth of the cranium (Fig. 1D–F). Routine perioperative antibiotics and post-operative subgaleal drainage were used for the cranioplasty. The postoperative course was uneventful, and follow-up CT scans performed 3 months (63 cm², Fig. 1G–I and 2 years (64 cm², 35% increase vs. after DC; 8% increase vs. before cranioplasty, Fig. 1J–L) after titanium cranioplasty revealed a stabilized defect size. This patient has been followed up for 6 years, and out-patient visits found no surgery-related complications as well as noting satisfactory school attendance and performance.

3.5. Illustrative case 2

Case 2 was a 12-year-old girl who had a cranial defect and was admitted for titanium mesh cranioplasty. On review of her medical history, she received a left frontal temporal parietal occipital DC because of traumatic brain injury 5 months ago. During the initial emergence decompression procedure, a left frontal temporal parietal occipital bone flap, measuring 120 cm² on CT (Fig. 2A–C), was removed. 3D CT reconstruction of the cranium for titanium mesh modelling before cranioplasty revealed only minimal enlargement of the defect to 123 cm² (3% increase, Fig. 2D–F). A routine cranioplasty technique was used and the postoperative course was uneventful. Follow-up CT scans performed 2 years after titanium cranioplasty revealed a stabilized defect size (128 cm², 7% increase vs. after DC; 4% increase vs. before cranioplasty, Fig. 2G–I). This patient has been followed up for 5 years and showed satisfactory school performance.

4. Discussion

Autogenous bone is considered the best reconstruction material in pediatric patients, but it is also associated with a high resorption rate and surgical site infection in children (Martin et al., 2014), and, in that case, a second cranioplasty with artificial material is usually required. In adults, various artificial materials, including titanium, PMMA, PEEK, hydroxyapatite, polythene and hydroxyapatite, have been used in the history of cranioplasty (Zins et al., 2010; Feroze et al., 2015). The advantages of titanium include biocompatibility, lightness, rigidity and excellent contour fit by modelling based on preoperative CT data, making it a popular choice in current clinical practice. Despite the wide use of titanium mesh in cranioplasty, there is still no consensus on the optimal reconstruction material in

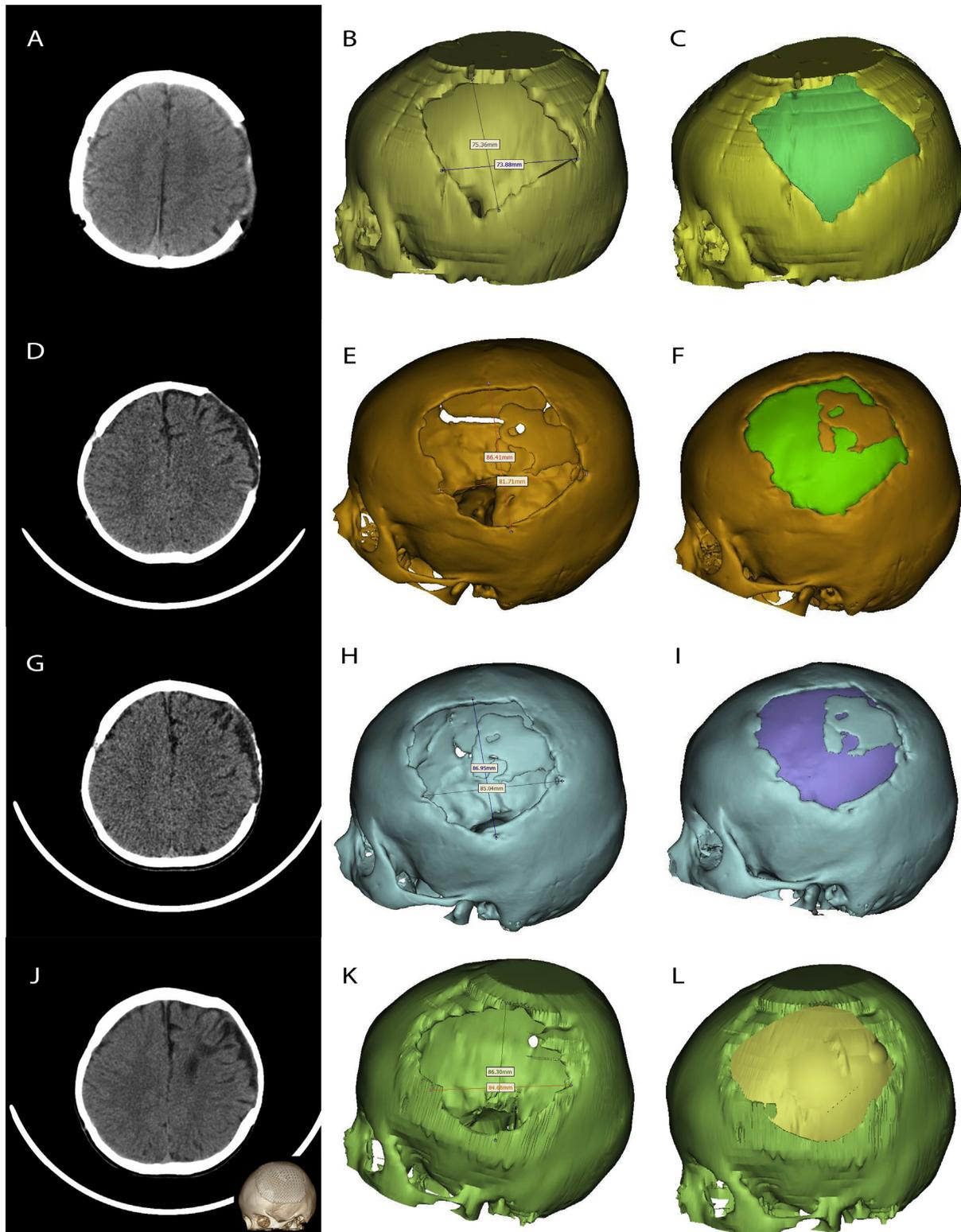


Fig. 1. Changes in the cranial defect size after decompressive craniectomy and titanium mesh cranioplasty in a preschooler patient. **A:** Computed tomography (CT) scan of a 3-year-old boy who underwent decompressive craniectomy because of traumatic brain injury. A left temporal parietal bone flap, measured 7.5 cm × 7.4 cm in the maximal diameter (**B**) and 47 cm² in area (**C**) on CT, was removed after evacuation of a left subdural haemorrhage. Note that a right bone flap was returned after evacuation of an epidural haemorrhage. **D:** By the time the patient reached 6 years of age, he was admitted for cranioplasty. 3D CT reconstruction of the cranium for titanium mesh modelling before cranioplasty revealed enlargement of defect to 8.6 cm × 8.2 cm in the maximal diameter (**E**) and 60 cm² in area (28% increase) (**F**) and partial regrowth of cranium. **G:** Follow-up CT scans performed 3 months after titanium cranioplasty revealed minimal increase in defect size: 8.7 cm × 8.5 cm in the maximal diameter (**H**), and 63 cm² in area (**I**). **J:** Follow-up CT scans performed 2 years after titanium cranioplasty (inlet showing the titanium mesh covering the defect) revealed stabilized defect size: 8.6 cm × 8.5 cm in the maximal diameter (**K**), and 64 cm² in area (**L**, 35% increase vs. after craniectomy; 8% increase vs. before cranioplasty).

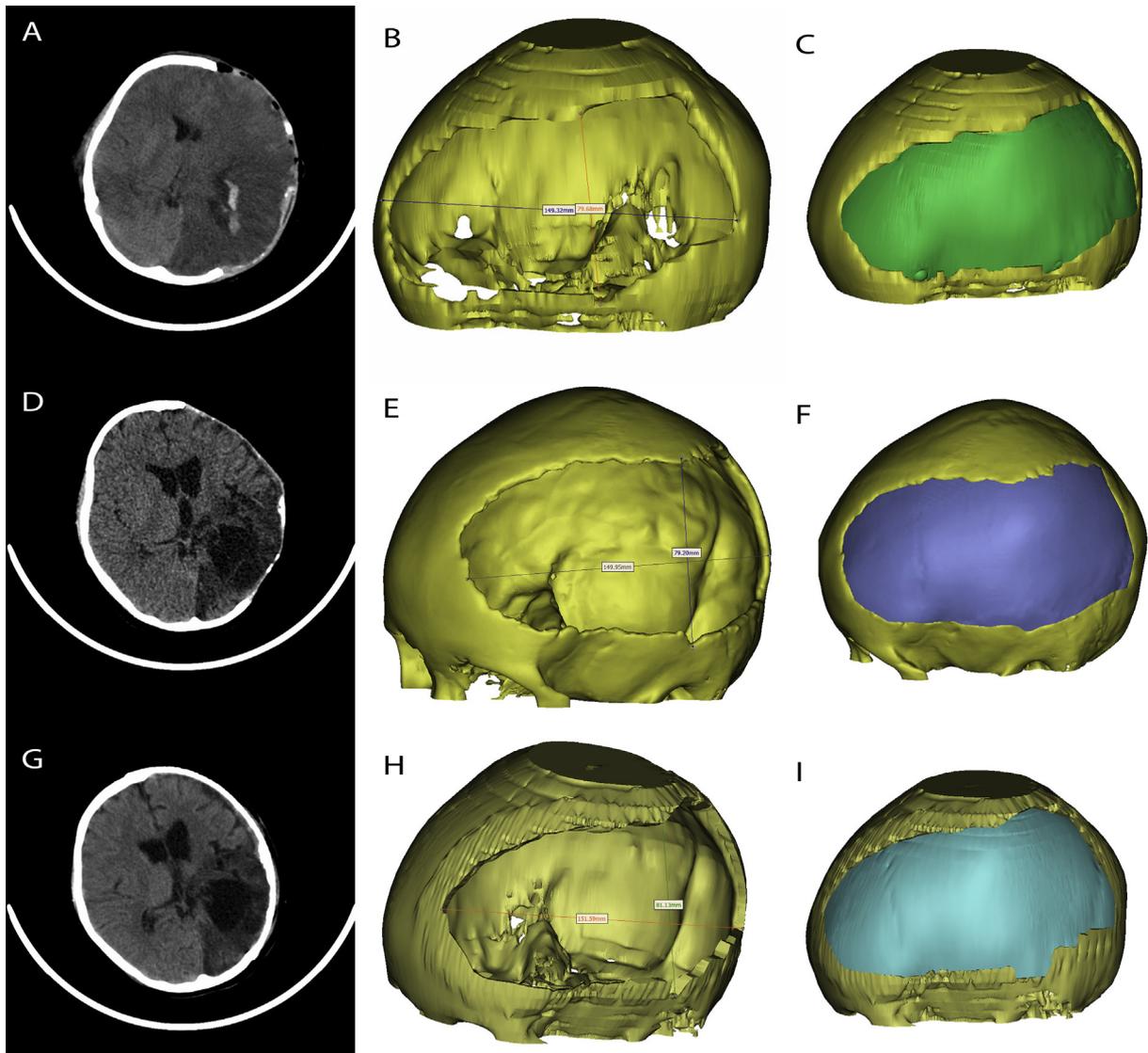


Fig. 2. Changes in the cranial defect size after decompressive craniectomy and titanium mesh cranioplasty in a school-age patient. **A:** Computed tomography (CT) scan of a 12-year-old girl who underwent decompressive craniectomy because of traumatic brain injury. A left frontal temporal parietal occipital bone flap, measured 14.9 cm \times 8.0 cm in the maximal diameter (**B**) and 120 cm² in area (**C**) on CT, was removed. **D:** Five months later, 3D CT reconstruction of the cranium for titanium mesh modelling before cranioplasty revealed only minimal enlargement of defect, 15.0 cm \times 7.9 cm in the maximal diameter (**E**) and 123 cm² in area (3% increase, **F**). **G:** Follow-up CT scan performed 2 years after titanium cranioplasty revealed stabilized defect size: 15.2 cm \times 8.1 cm in the maximal diameter (**H**) and 128 cm² in area (7% increase vs. after craniectomy; 4% increase vs. before cranioplasty, **I**).

pediatric patients (Josani et al., 2005). In a systematic review by Rocque et al. (2013), the authors concluded that there might be a significant effect of the cranioplasty material on the post-operative complication rate in pediatric populations with prior decompressive craniectomy. Our results demonstrate that cranioplasty with customized 3D titanium mesh is a feasible solution with good long-term success rates in pediatric patients and thus provides evidence to support future clinical practice.

Timing of cranioplasty in pediatric population is still an unsolved issue. Piedra et al. suggested that early (<6 weeks) autologous cranioplasty reduces the occurrence of bone resorption and subsequent reoperation (Piedra et al., 2012). Waqas et al. showed no association of complication rate with the timing of cranioplasty (Waqas et al., 2017). However, in their cohort only 1 patient received a titanium mesh repair. One of the major concerns with using titanium in children is that metal cannot grow with children's skulls, leading to potential asymmetry and even deformity in the

calvarial contour. For example, there are reports of migration of mini-plates in infants who were treated for craniosynostosis (Papay et al., 1995; Kosaka et al., 2003). The skull defects resulted from craniectomy for trauma patients are usually large in order to deliver adequate decompression on the swollen brain. Therefore, it is justifiable to be concerned about applying a large area of titanium mesh to repair the defects in a growing child's cranium. According to normal growth curve of children, they can reach about 90% of their adult cranial size by the age of 5 and almost complete growth at age 6. Unfortunately, there is paucity of data on accurate measurement of changes in cranial defect size in growing children by imaging modalities such as CT, probably due to ethical concerns over exposing children to unnecessary radiation exposure. We assessed the growth of the cranium by analysing the data collected during preoperative CT for craniectomy, cranioplasty as well post-operative CT follow-up and therefore no patient was exposed to treatment-irrelevant radiations. Our results showed for the first

time that, despite signs of regrowth of cranium in some patients, there were significant enlargements of cranial defect sizes in pre-schooler patients but minimal changes in school age children. Based on this knowledge, we proposed postponing cranioplasty with titanium mesh until the age of 6 if conditions allowed, the time that most children would go to primary school and enter a new stage of life. Reconstruction of cranium before school enrollment would not only protect their brains during school activities but would also reduce the social isolation that they experience for esthetic concerns regarding their appearances. Parents reported the high school attendance rate of the school-age children and satisfaction about school performance during follow-up visits. Therefore, this timing of cranioplasty that we proposed in pediatric patients is a feasible option in selected patients.

Williams et al. (2015) showed, in a series of 151 adult patients who had custom-made titanium cranioplasty, that implant removal (due to Infection) was seen in only 4% of cases. Williams et al. (2016) further analysed data from 22 children and adolescent patients and found no significant complication related to surgeries at both early and long-term (average 4.5 years) follow-up. More recently, Ma et al. (2018) examined the outcomes of titanium mesh cranioplasty in 33 pediatric patients and showed favourable interim outcomes, given the few complications and no evidence of growth restriction. One patient in our series had late complications (>6 months) of implant exposure, but these might be related to either remains of bone debris during the initial DC or poor scalp blood supply instead of microorganism infections (Sheng et al., 2017). Previous studies have suggested that the integrity of vascularity in the overlying scalp is the most important determinant of postoperative infection or implant exposure (Baumeister et al., 2008; Cheng et al., 2008; Kim et al., 2013). Various factors, such soft tissues trauma and scarring, number of previous incisions, and radiation exposure, would impair the blood supply of the scalp and wound healing. In our patients, most had satisfactory scalp conditions before cranioplasty, which might explain why there was no infection during the perioperative period.

The major limitation of this study is the small sample size of each patient cohort and the existence of intrinsic heterogeneity within each group due to the nature of traumatic events. In order to obtain a more definitive conclusion on what is the best timing of cranioplasty in either group, future study should aim to enroll a much larger sample number and include more heterogenous patients such as those challenged by requiring VP shunts for a CSF disturbance after decompressive craniectomy. Second, there was a lack of objective modalities to measure neurological functions and learning and cognitive performances of these children on follow-up in our study. Functional magnetic resonance imaging is a radiation-free radiological tool, but it is expensive, time consuming and might be interfered with by titanium implants. Another drawback is lack of a patient group undergoing repair with autologous bone flap, and thus a direct comparison cannot be made between the two materials. In addition, without a direct comparison between early repair and delayed repair of cranial defects in the pre-schoolers, we cannot rule out the possible negative impacts of delayed repair on their brain developments. Finally, delayed repair would also require more time and energy from their school attendance to be devoted to protecting their vulnerable brain tissues.

5. Conclusion

We have shown satisfactory clinical outcomes and low complication rates associated with customized 3D titanium mesh cranioplasty in pediatric patients with previous craniectomy for traumatic brain injury. The growth of cranial defect sizes suggests postponing the timing of cranioplasty until 6 years of age for pre-

schoolers, when more active social life and school enrollment are required.

Conflicts of interest

None of the authors has any potential conflict of interest.

Acknowledgements

This study was supported by the Science and Technology Department of Zhejiang Province (Grant No. 2016C33213 and 2015C33144) and Natural Science Foundation of Ningbo (Grant No. 2018A610256).

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jcms.2019.04.009>.

References

- Baumeister S, Peek A, Friedman A, Levin LS, Marcus JR: Management of post-neurosurgical bone flap loss caused by infection. *Plast Reconstr Surg* 122: 195e–208e, 2008
- Cheng YK, Weng HH, Yang JT, Lee MH, Wang TC, Chang CN: Factors affecting graft infection after cranioplasty. *J Clin Neurosci* 15: 1115–1119, 2008
- Chong SL, Khan UR, Santhanam I, Seo JS, Wang Q, Jamaluddin SF, et al: A retrospective review of paediatric head injuries in Asia—a Pan Asian Trauma Outcomes Study (PATOS) collaboration. *BMJ Open* 7: e015759, 2017
- Feroze AH, Walmsley GG, Choudhri O, Lorenz HP, Grant GA, Edwards MS: Evolution of cranioplasty techniques in neurosurgery: historical review, pediatric considerations, and current trends. *J Neurosurg* 123: 1098–1107, 2015
- Fu KJ, Barr RM, Kerr ML, Shah MN, Fletcher SA, Sandberg DI, et al: An outcomes comparison between autologous and alloplastic cranioplasty in the pediatric population. *J Craniofac Surg* 27: 593–597, 2016
- Halani SH, Chu JK, Malcolm JG, Rindler RS, Allen JW, Grossberg JA, et al: Effects of cranioplasty on cerebral blood flow following decompressive craniectomy: a systematic review of the literature. *Neurosurgery* 81: 204–216, 2017
- Jeyaraj P: Importance of early cranioplasty in reversing the “Syndrome of the trephine/motor trephine syndrome/sinking skin flap syndrome”. *J Maxillofac Oral Surg* 14: 666–673, 2015
- Jiang JY: Chinese head trauma study C: head trauma in China. *Injury* 44: 1453–1457, 2013
- Josan VA, Sgouros S, Walsh AR, Dover MS, Nishikawa H, Hockley AD: Cranioplasty in children. *Childs Nerv Syst* 21: 200–204, 2005
- Kim H, Sung SO, Kim SJ, Kim SR, Park IS, Jo KW: Analysis of the factors affecting graft infection after cranioplasty. *Acta Neurochir (Wien)* 155: 2171–2176, 2013
- Kosaka M, Miyanohara T, Wada Y, Kamiishi H: Intracranial migration of fixation wires following correction of craniostylosis in an infant. *J Craniofac Surg* 31: 15–19, 2003
- Ma IT, Symon MR, Bristol RE, Beals SP, Joganic EF, Adelson PD, et al: Outcomes of titanium mesh cranioplasty in pediatric patients. *J Craniofac Surg* 29: 99–104, 2018
- Martin KD, Franz B, Kirsch M, Polanski W, von der Hagen M, Schackert G, et al: Autologous bone flap cranioplasty following decompressive craniectomy is combined with a high complication rate in pediatric traumatic brain injury patients. *Acta Neurochir (Wien)* 156: 813–824, 2014
- Mukherjee S, Thakur B, Haq I, Hettige S, Martin AJ: Complications of titanium cranioplasty - a retrospective analysis of 174 patients. *Acta Neurochir (Wien)* 156: 989–998, 2014 Discussion 998
- Narayan D, Persing JA: Cosmetic concerns in pediatric craniofacial surgery. *Neurosurg Clin N Am* 13: 505–513, 2002 vi
- Papay FA, Hardy S, Morales Jr L, Walker M, Enlow D: “False” migration of rigid fixation appliances in pediatric craniofacial surgery. *J Craniofac Surg* 6: 309–313, 1995
- Piedra MP, Thompson EM, Selden NR, Ragle BT, Guillaume DJ: Optimal timing of autologous cranioplasty after decompressive craniectomy in children. *J Neurosurg Pediatr* 10: 268–272, 2012
- Piitulainen JM, Kauko T, Aitasalo KM, Vuorinen V, Vallittu PK, Posti JP: Outcomes of cranioplasty with synthetic materials and autologous bone grafts. *World Neurosurg* 83: 708–714, 2015
- Plum AW, Tatum SA: A comparison between autograft alone, bone cement, and demineralized bone matrix in cranioplasty. *Laryngoscope* 125: 1322–1327, 2015
- Rocque BG, Amancherla K, Lew SM, Lam S: Outcomes of cranioplasty following decompressive craniectomy in the pediatric population. *J Neurosurg Pediatr* 12: 120–125, 2013
- Shah AM, Jung H, Skirboll S: Materials used in cranioplasty: a history and analysis. *Neurosurg Focus* 36: E19, 2014

- Sheng H-S, Shen F, Wang M-D, Lin J, Lin F-C, Yin B, et al: Titanium mesh implants exposure after cranioplasty in two children: involvement of osteogenesis? *Chin Neurosurg J* 3: 8, 2017
- Waqas M, Ujjan B, Hadi YB, Najmuddin F, Laghari AA, Khalid S, et al: Cranioplasty after craniectomy in a pediatric population: single-center experience from a developing country. *Pediatr Neurosurg* 52: 77–79, 2017
- Williams L, Fan K, Bentley R: Titanium cranioplasty in children and adolescents. *J Craniomaxillofac Surg* 44: 789–794, 2016
- Williams LR, Fan KF, Bentley RP: Custom-made titanium cranioplasty: early and late complications of 151 cranioplasties and review of the literature. *Int J Oral Maxillofac Surg* 44: 599–608, 2015
- Xuequn Y, Ke L, Ivers R, Du W, Senserrick T: Prevalence rates of helmet use among motorcycle riders in a developed region in China. *Accid Anal Prev* 43: 214–219, 2011
- Zins JE, Langevin CJ, Nasir S: Controversies in skull reconstruction. *J Craniofac Surg* 21: 1755–1760, 2010